

Numerical simulation of flow for the improvement of the access channel to the port of Quila (Barranguila) in Colombia by using T form Groyne structure

Mehdi Nezhadnaderi¹, Kiyanoosh Guilaninezhad², Mohammad Hossein Vafaei³, Babak Pordel Maragheh⁴, Babak Fazli Malidareh⁵, Ali Sheykhbahaei⁶, Abolfazl Bagheri⁷ and Seyed Mohammad Mousavi⁸

¹ Department of Civil Engineering, Tonekabon Branch, Islamic Azad University, Tonekabon, Iran. (Corresponding Author). mehdi2930@yahoo.com.

² Department of Civil Engineering, Tonekabon Branch, Islamic Azad University, Tonekabon, Iran. saman.mohareri@yahoo.com

³ Assistant Professor, Department of Civil Engineering, Pooyesh Institute of Higher Education, Qom, Iran. M.h.vafaei2024@gmail.com

⁴ Department of Civil Engineering, Ardabil Branch, Islamic Azad University, Ardabil, Iran. civil_babak2005@yahoo.com

⁵ Department of Civil Engineering, Babol Branch, Islamic Azad University, Babol, Iran. Fazli.babak@babolia.ac.ir

⁶ PhD Candidate in Physical Oceanography at university of Hormozgan/ Iranian National Institute for Oceanography and Atmospheric science, Ali.sheykhbahaei@inio.ac.ir

⁷ Department of Civil Engineering, Tonekabon Branch, Islamic Azad University, Tonekabon, Iran. Abolfazl.Bagheri@yahoo.com

⁸ Department of Civil Engineering, Tonekabon Branch, Islamic Azad University, Tonekabon, Iran. Mosavi.622@gmail.com

ARTICLE INFO

Article History:

Received: 29 Oct. 2023

Accepted: 13 April 2024

Keywords:

T form Groyne

Flow pattern

Secondary currents

90 Degree bend

ABSTRACT

Barranguila is located on the left bank of the Magdalena River, about 22 km from the outskirts of the mouth. The river flows in the direction of the north to the Caribbean. Measures were taken to create a duct with a width of 150 meters and a depth of 9.2 meters in the river. In this research, the factors affecting the sedimentation and erosion process in terms of structural modifications in the access channel were investigated using numerical methods. In the present study, the numerical results of the effect of non-volumetric spray drift with 90° T-shaped spray guns, relative to the external wall of an arch with a length of 15 channel width, on the average velocity distribution and shear stress in a 90° gentle arch with a ratio of $R/B = 4$, 0.7 m wide and 0.14 m water depth. The results of the study showed that the presence of a spur gear causes uniformity of upstream velocity and high-speed transmission from the outer wall to the middle of the canal to the inner wall. The shear stress of the bed is increased due to the presence of a spray gun but has little effect on the location of the shear stress incidence. As it can be seen, the negative pressure in the outer arc is increased and in the external arc exposed to erosion due to the high forces caused by positive pressure, the reduction of the Groyne is reduced and the conditions for the stabilization of the bed are provided. As can be seen, in the inner arc, after the construction of a Groyne, a negative pressure increases as well, and the ability to precipitate in this area also increases.

1. Introduction

The changes in the bed and banks in the river bend are of great importance from the point of view of morphology and river engineering. One way to stabilize the external bend is to use breakwater structures. The port of Barranquilla is located on the left bank of the Magdalena River, approximately 22 km upstream of its mouth. The river flows in a near-north direction and empties into the Caribbean Sea. Until 1972, the river had only one access channel for navigation, and it accepted vessels with a draft of up to 10 m. From 1970 onwards, adverse morphological changes forced the government to carry out emergency dredging operations. In 1986, the Ministry of Public Works signed a contract with the University of the North and the Hydraulic Laboratory of Las Flores to study the problem and design corrective measures. The project aimed to design arrangements for the creation of a channel 150 m wide and 2.9 m deep. In 1987, a team of engineers from Haskoning and the Delft Hydraulic Institute of the Netherlands joined the Colombian team. Several solutions were identified, such as constructing a non-permeable guide dam, a sand dam, and difficult spots in the river, and removing the recently created fill area. In this research, the factors affecting scour in the conditions of corrective structures in the desired access channel will be investigated using a numerical method.

Breakwaters are usually constructed to protect shores or to provide sufficient depth for navigation purposes. Known by names such as epis, groynes, and cross arms, these structures can be grouped by their shape, such as T-shaped or L-shaped.

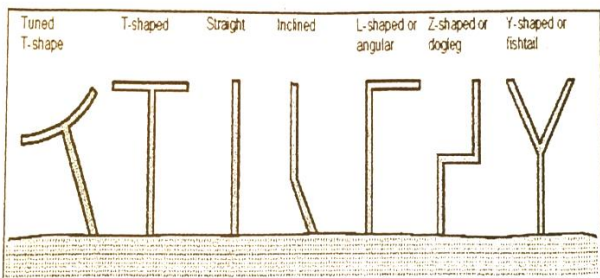


Figure 1 - Types of breakwaters that so far have been built

The most important parameters that should be considered in the design of breakwaters are: breakwater design plan, breakwater length, distance between breakwaters, orientation with the flow path, crest height, slope of the bank, materials used in the breakwater section.

- Breakwater length

The length used for the breakwater is usually calculated in the intervals between the committee rate and the maximum flow depth and is usually about a quarter of the average width of the desired bank.

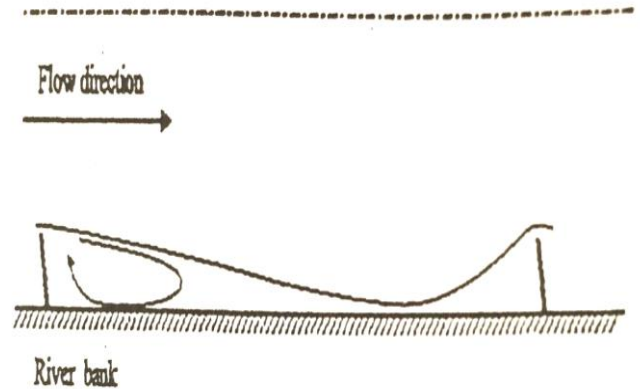


Figure 2- Flow pattern in the field of breakwaters with very small aspect ratio.

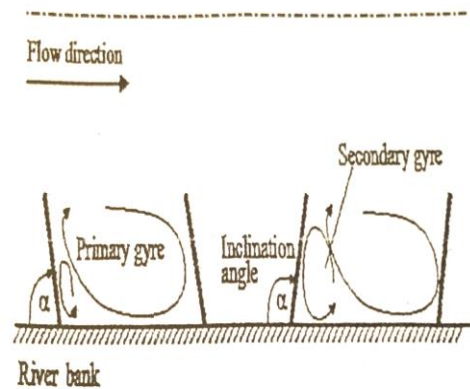


Figure 3- View of breakwaters with different angles and how the flow moves in their area.

In 2013, Div Salar and Mousavi Jahromi studied the effect of increasing the wing length of an L-shaped breakwater on the scour around it in a 90-degree arc.

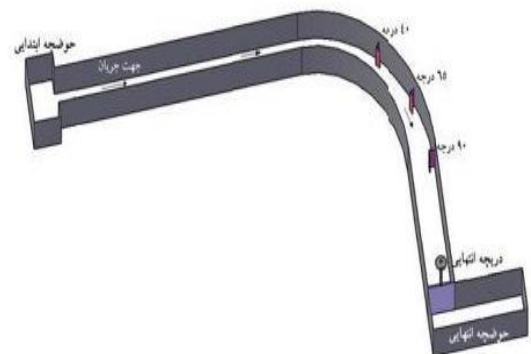


Figure 4- Schematic of the laboratory flume used (Divsalar and Mousavi Jahromi, 2013).



Figure 5- Schematic of the laboratory flume used and the used sluice gate samples (Divsalar and Mousavi Jahromi, 2013).



Figure 6- Example of the experiment (Sluice gate L with wing size 10.5 cm, $Q=4.25$ liters per second and $\phi=90$ degrees of bed before and after scouring (Divsalar and Mousavi Jahromi, 2013).

In 2009, Vaghefi et al. studied the temporal changes in scour around a T-shaped breakwater in a 90-degree arc.

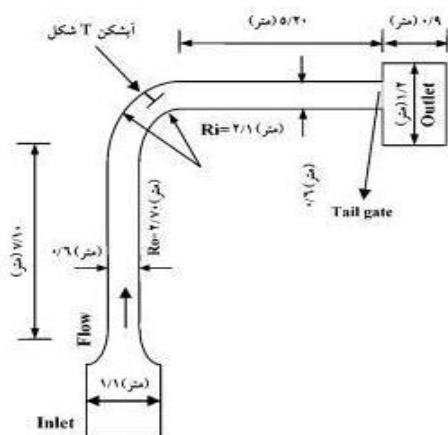


Figure 7- Laboratory sciences used by Vaghefi et al. 2009

In 2015, Vaghefi et al. studied the effect of supporting structures on the flow pattern around T-shaped sluice gates in a 90-degree bend.

In 2015, Vaghefi et al. studied a laboratory study of turbulent flow in a 180-degree bend.

In 2012, Mehrnahad and Ghodsian studied the effect of the parameters of sluice gate length and material diameter on scour around a T-shaped sluice gate located in a 90-degree bend.

In 2009, Ghodsian and Vaghefi studied a laboratory study of scour and flow around a T-shaped sluice gate in a 90-degree bend. Experimental research was conducted to investigate the bed in the bend and its protection using gravel. The experiments were conducted in a 90-degree bend with sediments with an average diameter of 0.34 and 1.18 mm. The results of this study show that the water mainly occurs in the outer arc of 90 degrees of horizontal maximum sedimentation and sedimentation occurs around 30 degrees of the middle section near the concave and convex part. During the downflow, the scour depth increases near the concave bank and its maximum value increases around the 30 degrees section. At further downstream, the scour depth decreases along the section. On the other hand, sedimentation occurs near the lower part of the convex channel from 20 degrees to 60 degrees. There is a transverse slope of the water surface within the section with a higher surface on the concave side. As a result of this transverse slope, the bottom water moves from the concave bank towards the convex focus while the surface water moves from the convex to the section.

In 2012, Vaghefi et al. studied the effect of Froude number on scour around a T-shaped weir in a 90-degree bend. This paper presents the results of experiments on scour around a T-shaped weir located in a 90-degree bend. The effect of the tooth length on the scour rate is investigated. The experiments are repeated in a rectangular channel. The results show that with increasing weir length, the maximum scour depth and the volume and dimensions of the scour hole increase. The location of the maximum scour depth occurs at a distance of about 10 to 20% of the length of the ponds upstream.

In 2009, Hosseini et al. conducted a field study of the condition of water structures in the Ghezal Ozan River [7].

Field visits to the project area show that the agricultural lands on the left bank have been restored and are well cultivated. Therefore, it was suggested that the structures be reviewed to continue protecting the lands in the critical area mentioned. It was also recommended that necessary measures be taken to strengthen the bodies of the apiaries located in the meanders of the arteries in order to prevent serious damage to these structures during floods. It was recommended that the number of river arteries and their meandering nature be examined in the management plans and that a final decision be made based on the morphology of the river. The use of a system of breakwaters and longitudinal embankments to control the river, prevent erosion of the banks, and restore new lands is recommended as a suitable model for managing rivers.

Using the results of field visits and technical and structural assessments of the reorganization plans can be very useful in identifying and reconstructing critical areas and damaged structures, improving the efficiency of the studied plan, and making future plans more effective. Therefore, it is suggested that the executive authorities pay special attention to this issue.



Figure 9- View of a constructed spillway in the Qezel Ozen-Qowijan River

Elyasi et al. (2011), using Flow3D software and applying the RNG $k-\epsilon$ turbulence model, simulated the flow pattern around a single submerged spillway in a straight inclined channel without considering the free surface and compared the results of the numerical model with experimental data. The results of this simulation, without considering the free surface, showed a good agreement with the experimental data. Comparison of the velocity profiles in the numerical model and the experimental results indicates the agreement of these data.

Mosteh and Atma (2004) investigated the effect of spillway length on the circulation zone behind the spillway by considering the scale effect with the Fluent software.

Shahrokhi (2008) prepared a numerical model of the flow pattern around a weir using Fluent software and applied different turbulence models to study the effect of these models on the length of the flow separation zone behind a weir. The most important result of this research shows that the LES turbulence model has the best agreement with the experimental results and this model provides a better prediction of the length of the separation zone behind the weir. Finally, it was suggested that the model be implemented in a wider range of changes in flow parameters, length and angle of installation of the weir.

Akhirya et al. (2011) conducted a numerical simulation of the hydraulic flow and sediment transport around various weirs. The modeling results showed that among the turbulence models, the RNG $k-\epsilon$ and $k-\epsilon$ models were closer to the experimental data, but the RNG $k-\epsilon$ turbulence model showed the best results for simulating the flow field around the weir.

Abbasi-Chenari et al. (2011) simulated the flow pattern around L-shaped breakwaters perpendicular to the shore using the Fluent software and the $k-\epsilon$ turbulence model. In this study, the L-shaped breakwater was impermeable and was placed non-submerged at 5 different angles of the river curve. The results indicate that the flow turbulence, the maximum velocity range, and ultimately the highest bed scouring occur at the breakwater tip. Also, with increasing discharge and Froude number, the maximum flow velocity range near the breakwater tip increases and its shape is stretched in the flow direction. Finally, it was concluded that the $k-\epsilon$ turbulence model has good accuracy in simulating the backflow areas downstream of the breakwater and the location of eddies and flow turbulence around the breakwater.

Ghanadan et al. (2012) numerically simulated the flow over a wide-edge lateral spillway using Fluent software and compared the results obtained from this software with experimental data. The results showed that among the turbulence models available in the software, the RNG $k-\epsilon$ turbulence model has a higher accuracy for simulating the flow over a lateral spillway. Also, using the calibrated model, the effect of changing the height and width of the spillway crest on the discharge passing through the spillway was investigated. Accordingly, it was concluded that the height of the wide-edge lateral spillway crest is more effective on the discharge value of the spillway outlet than the crest width.

2. Methods

The port of Barranquilla is located on the left bank of the Magdalena River, approximately 22 km upstream of its mouth. The river flows in a northerly direction and empties into the Caribbean Sea. Until 1972, the river had only one navigable channel, admitting vessels with a draft of up to 10 m. Since 1970, adverse morphological changes have forced the government to undertake emergency dredging operations. In 1986, the Ministry of Public Works signed a contract with the University of the North and the Las Flores Hydraulic Laboratory to study the problem and design corrective measures. The project aimed to design arrangements for the creation of a channel 150 m wide and 2.9 m deep. In 1987, a team of engineers from Haskoning and the Delft Hydraulic Institute in the Netherlands joined the Colombian team. Several solutions were identified, such as the construction of the Natrava guide dam, a sand dam, and the removal of the recently created embankment. In this study, the factors affecting scour in the conditions of corrective structures in the desired access channel will be investigated using a numerical method. The figures below show the location of the Magdalena River in Colombia.



Figure 10 - Location of the Magdalena River and the port of Barranquilla in Colombia



Figure 13- Location of the Magdalena River and the port of Barranquilla in Colombia

To solve the flow using computational fluid dynamics, the following steps must be performed (Shojaifard and Noorpour Hashtroodi, 1995):

- Selecting the Gambit model to create the geometry
- Selecting the computational model
- Selecting the calculation solution method in the model
- Selecting the basic equations to solve
- Determining the physical characteristics of the materials
- Determining the boundary conditions
- Specifying the problem solving parameters
- Making an initial guess in the entire solution field
- Performing the solution and outputting the calculations.

3. Results and Discussions

In this study, Gambit software version 3.3.2 was used to generate the geometry and mesh it. The mesh pattern was Quad element and map type was used for the surfaces. The existing boundary conditions are velocity input from the left side from the top of the arc and pressure output boundary condition at the bottom of the arc outlet. The simulation results from Fluent software are seen in Figures 14 to 22.



Figure 11 - Location of protective structures at the beginning of the access channel to the Barranquilla port in Colombia



Figure 12 - Location of the Magdalena River and the port of Barranquilla in Colombia

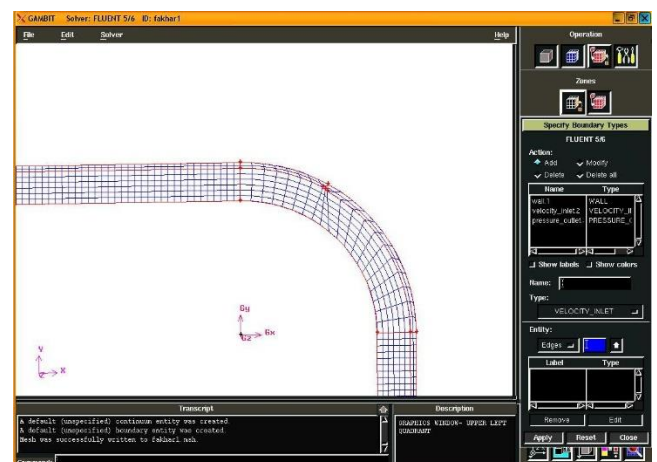


Figure 14 - Mesh pattern in the arch in the presence of a T-shaped breakwater with a length of 15% of the channel width at an angle of 30 degrees to the y-axis.

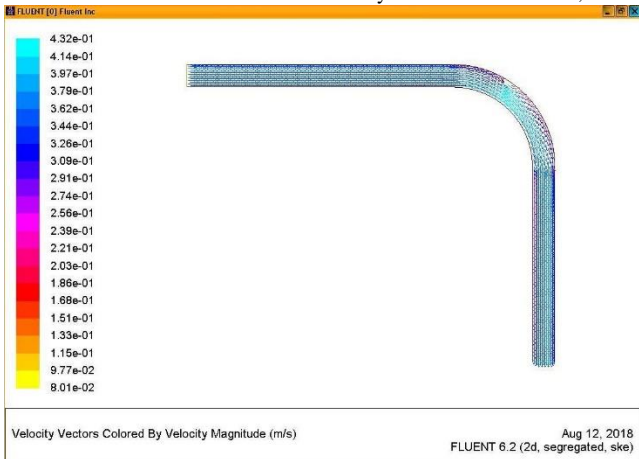


Figure 15- Average velocity distribution pattern in the curve in the presence of a T-shaped breakwater with a length of 15% of the channel width at an angle of 30 degrees to the y-axis.

As can be seen, the velocity in the inner arch increases, and in the outer arch, which has been subject to erosion due to high forces resulting from positive pressure, it decreases with the construction of the breakwater, and conditions are created for bed stabilization.

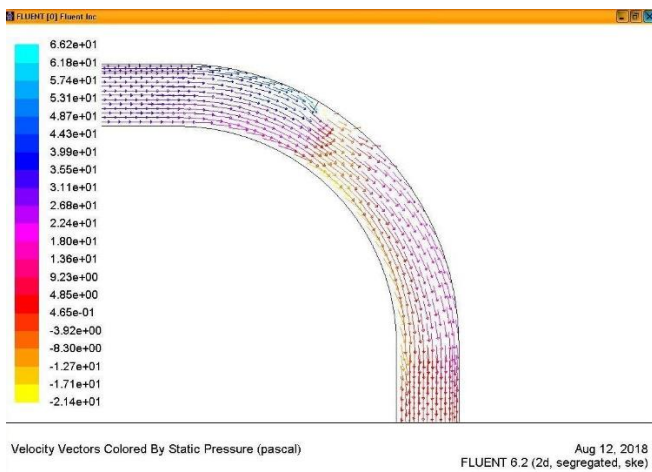


Figure 16 - Pressure distribution pattern in the arch in the presence of a T-shaped breakwater with a length of 15% of the channel width at an angle of 30 degrees to the y-axis.

As can be seen, the negative pressure in the outer arch increases, and in the outer arch, which was exposed to erosion due to high forces caused by positive pressure, it decreases with the construction of the breakwater, and conditions are provided for bed stabilization. As can be seen, the negative pressure in the inner arch also increases after the construction of the breakwater, which also increases the ability to deposit sediment in this area.

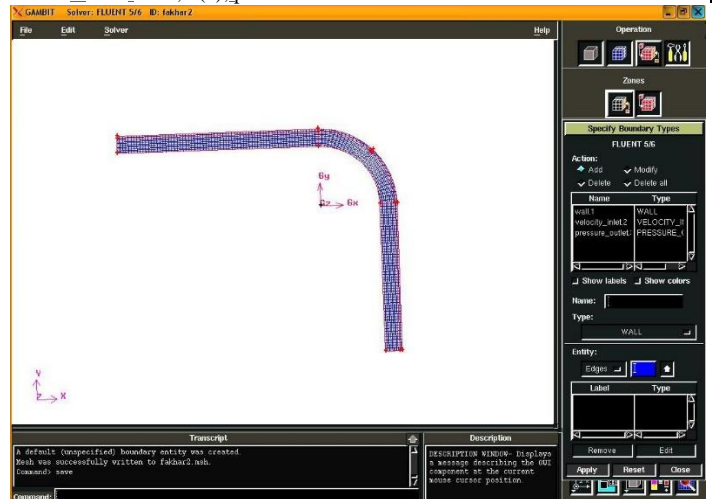


Figure 17 - Mesh pattern in the arch in the presence of a T-shaped weir with a length of 15% of the channel width at an angle of 45 degrees to the y-axis.

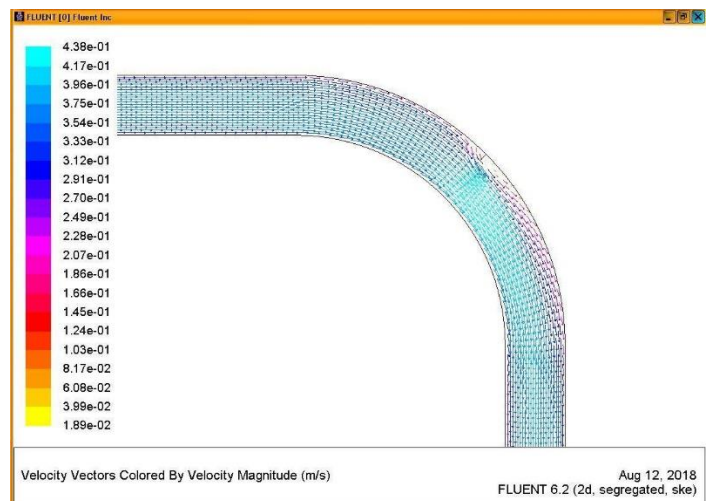


Figure 18 - Velocity distribution pattern in the curve in the presence of a T-shaped breakwater with a length of 15% of the channel width at an angle of 45 degrees to the y-axis.

As can be seen, the velocity in the inner arch increases, and in the outer arch, which has been subject to erosion due to high forces resulting from positive pressure, it decreases with the construction of the breakwater, and conditions are created for bed stabilization.

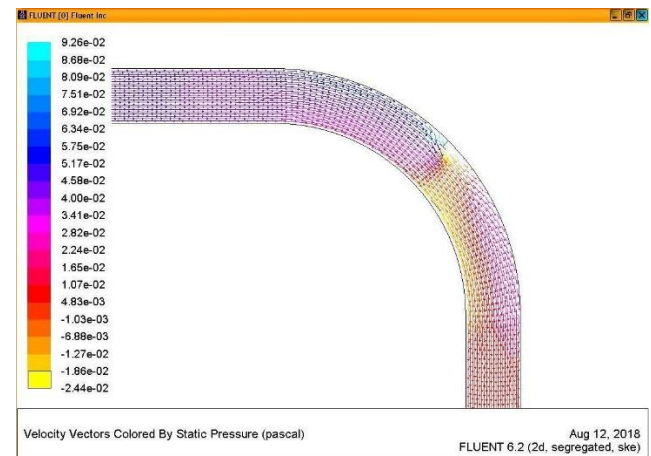


Figure 19- Pressure distribution pattern in the arch in the presence of a T-shaped breakwater with a length of 15% of the channel width at an angle of 45 degrees to the y-axis.

As can be seen, the negative pressure in the outer arch increases and in the outer arch part that has been exposed to erosion due to high forces caused by positive pressure, it decreases with the construction of the breakwater and conditions are provided for bed stabilization. As can be seen, the negative pressure in the inner arch also increases after the construction of the breakwater, which also increases the sedimentation ability in this area.

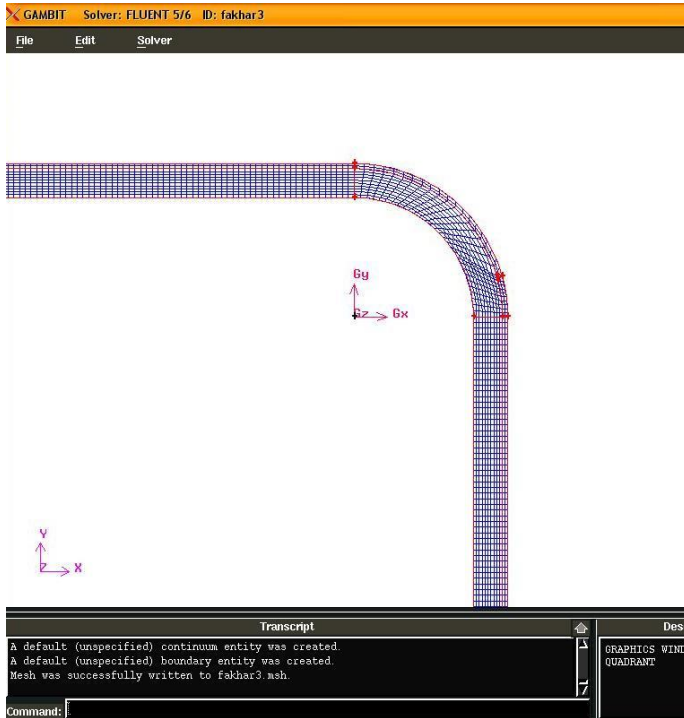


Figure 20 - Pressure distribution pattern in the arch in the presence of a T-shaped breakwater with a length of 15% of the channel width at an angle of 75 degrees to the y-axis.

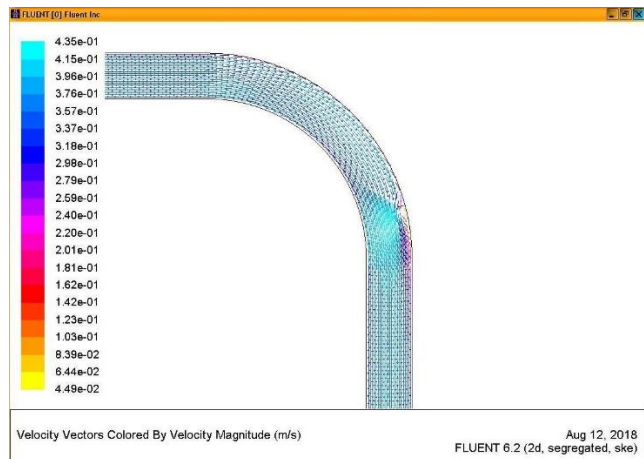


Figure 21- Velocity distribution pattern in the arch in the presence of a T-shaped breakwater with a length of 15% of the channel width at an angle of 75 degrees to the y-axis.

As can be seen, the negative pressure in the outer arch increases and in the outer arch part that has been exposed to erosion due to high forces caused by positive pressure, it decreases with the construction of the breakwater and conditions are provided for bed stabilization. As can be seen, the negative pressure in

the inner arch also increases after the construction of the breakwater, which also increases the sedimentation ability in this area.

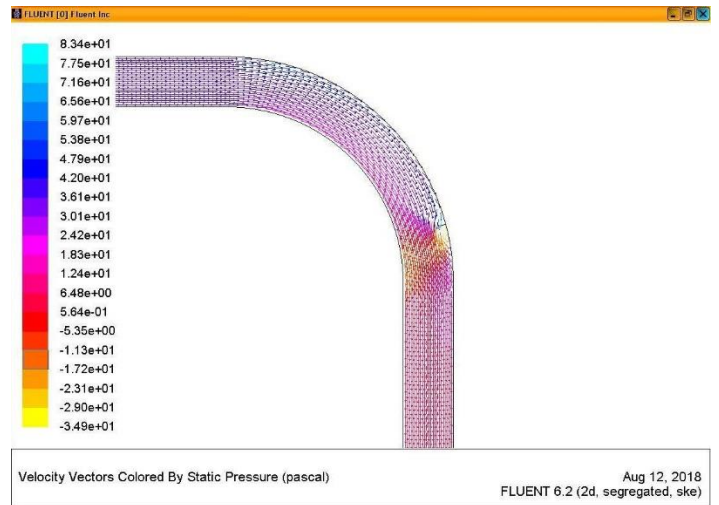


Figure 22- Pressure distribution pattern in the arch in the presence of a T-shaped breakwater with a length of 15% of the channel width at an angle of 75 degrees to the y-axis.

As can be seen, the negative pressure in the outer arch increases and in the outer arch part that has been exposed to erosion due to high forces caused by positive pressure, it decreases with the construction of the breakwater and conditions are provided for bed stabilization. As can be seen, the negative pressure in the inner arch also increases after the construction of the breakwater, which also increases the sedimentation ability in this area.

4. Conclusions

The aim of the present study is to investigate the effect of the presence of a breakwater in the arch on the flow pattern. For this purpose, the data obtained from the two-dimensional velocity acquisition were analyzed. The overall results of this numerical study can be stated as follows: the velocity distribution pattern in the arch indicates the concentration of areas with maximum velocity downstream of the arch and in the vicinity of the outer wall, which indicates the importance of protecting these areas by breakwaters. The use of breakwaters has made the velocity distribution upstream of the breakwater uniform, and also caused the high-velocity area to be transferred to the middle of the channel and the inner wall, but the placement of the breakwater increases the flow velocity in the channel compared to the case of the arch without breakwaters. According to the results in both cases, the main cause of erosion of the outer bank of the arch is the concentration of high-velocity areas in the final third of the arch, which, as can be seen, the placement of the breakwater has effectively prevented the formation of these areas. The speed in the vicinity of the outer bank of the arch is greatly reduced and the placement of the

breakwater causes the dispersion and transfer of the high-speed zone from the outer wall to the middle of the channel and the inner bank. According to Figures 15 to 22, the speed changes in the vicinity of the breakwater noses change rapidly and high speeds are located a short distance from the breakwater noses. This shows that protecting the breakwater noses is inevitable to maintain the stability of the breakwater structure.

According to the velocity distributions presented in Figures 15 to 22, in this case, high-velocity zones dominate over a large area of the arch near the inner wall. Figures 15 to 22 represent the average velocity distribution in the arch in the presence of a breakwater with a length of 15% of the channel width. Considering the shape of the T-shaped breakwaters, they also protect it by moving high-velocity layers away from the outer wall of the arch.

5. References

1. Ghodsian, M., & Vaghefi, M. (2009). Experimental study on scour and flow field in a scour hole around a T-shaped spur dike in a 90° bend. *Int. J. Sediment. Res.* 24(2): 145-158.
2. Tang, X. L., Chen, Z. C., & Yang, F. (2006). Dynamic large eddy simulation of secondary flow near a groyne. *Int. J. Nonlinear. Sci. and Num. Simul.* 7(3): 257-262.
3. Vaghefi, M., Akbari, M., & Fiouz, A. R.. (2015). An experimental study of mean and turbulent flow in a 180degree sharp open channel bend: secondary flow and bed shear stress. *KSCE J. Civil. Eng.* 20 (4):1582-1593.
4. Vaghefi, M., Ghodsian, M., & Adib, A. (2012). Experimental study on the effect of Froude Number on temporal variation of scour around a T-shaped spur dike in a 90 degree bend. *App. Mech. and Material* 147: 75-79.
5. Vaghefi, M., Ghodsian, M., & Salehi Neyshaboori, S. A. A. (2009). Experimental study on the effect of a T-shaped spur dike length on scour in a 90 degree cannel bend. *Arab. J. Sci. and Eng.* 34(2B): 337-348.
6. Vaghefi, M., Ghodsian, M., & Salehi Neyshaboori, S. A. A. (2012). Experimental study on scour around a T-Shaped spur dike in a channel bend. *J. Hydraul. Eng.* 138(5): 471-474.
7. Ahmad, M. (1951). Spacing and protection of spurs for bank protection. *Civil Eng. and Public. Rev.* 46: 3-7.
8. Vaghefi, M., Mohsenimehr, V. A., & Akbari, M. (2014). Numerical investigation of wing to web length ratios parameter of T-shaped spur dike in a 90 degree bend on scour pattern. *J. River. Eng.* 2(3): 45-52.
9. Vaghefi, M., Safarpour, Y., & Hashemi, S. S. (2015). Effects of relative curvature on the scour pattern in a 90° bend with a T-shaped spur dike using a numerical method. *Int. J. River. Basin. Manag.* 13(4): 501-514.
10. Vaghefi, M., Shakerdargah, M., & Akbari, M. (2014). Numerical investigation of the effect of Froude number on flow pattern around a submerged T-shaped spur dike in a 90° bend. *Turk. J. Eng. and Env. Sci.* 38(2): 266-277.
11. Yang, S. Q. (2005). Interactions of boundary shear stress, secondary currents and velocity. *Fluid. Dynamic. Res.* 36: 121-136.
12. Shojafard, M.J. & Noorpar Hashtroudi, A. S. (translators). 2000. Versteeg, H.K. & Mallalaskara, (1995). *Introduction to Computational Fluid Dynamics*", Iran University of Science and Technology Publications, Tehran.
13. Div Salar, A., & Mousavi Jahromi, H. (2014). Study of the effect of increasing the wing length of an L-shaped gully on the scour around it in a 90-degree bend. *Scientific and Research Journal of Irrigation Sciences and Engineering*, 37(3), Pages 53-61.
14. Vaghefi, M., Ghodsian, M. & Salehi Neyshaburi, A. (2009). Study of temporal changes in scour around a T-shaped gully in a

90-degree bend. *Journal of Water and Soil Conservation Research*, 16(1).

15. Mehrnohad, A., & Ghodsian, M. (2012). Laboratory study of the effect of gully length and material diameter parameters on scour around a T-shaped gully located in a 90-degree

bend, *Scientific and Research Journal of Iranian Water Resources Research*, 8(8).